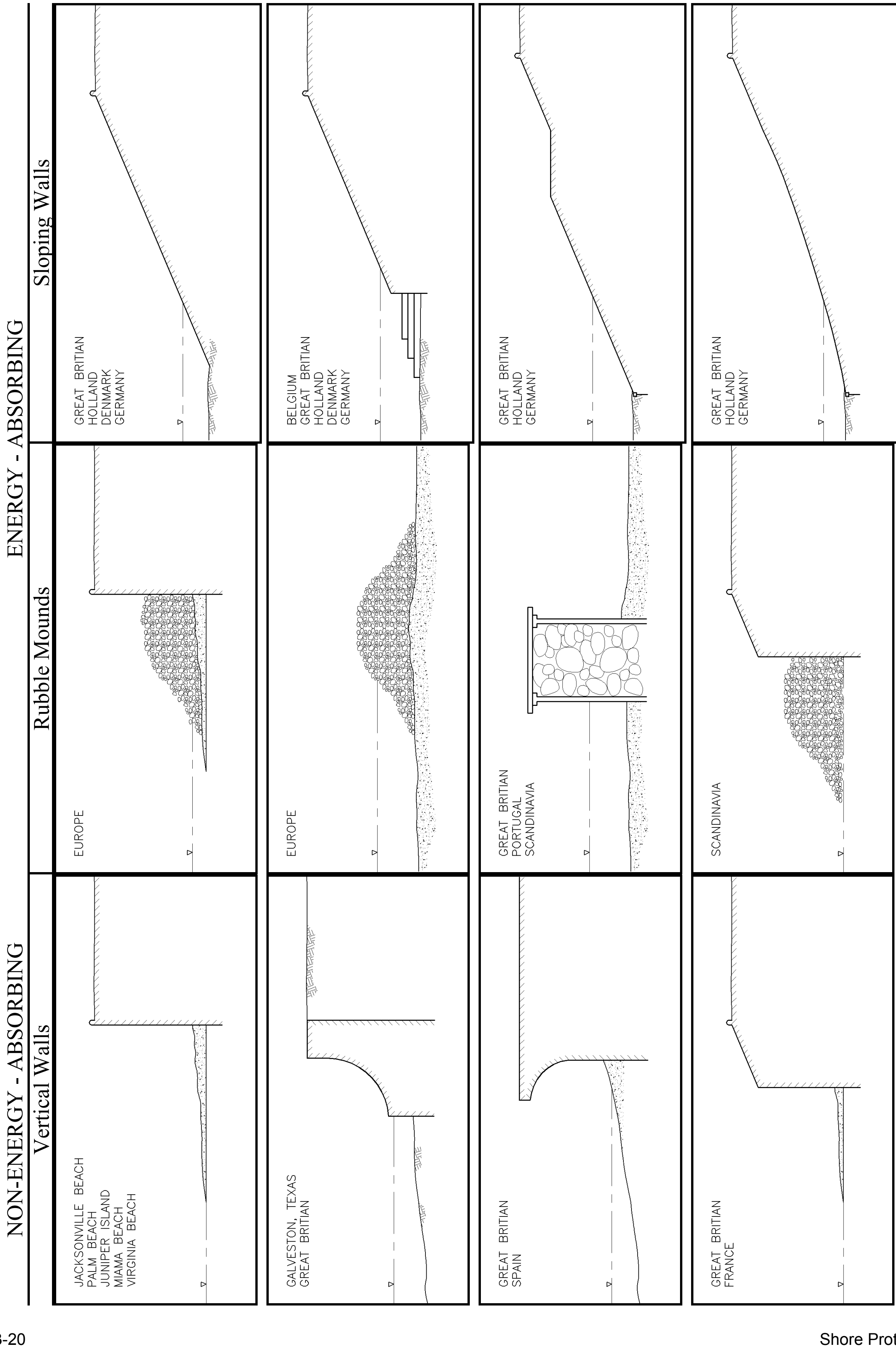


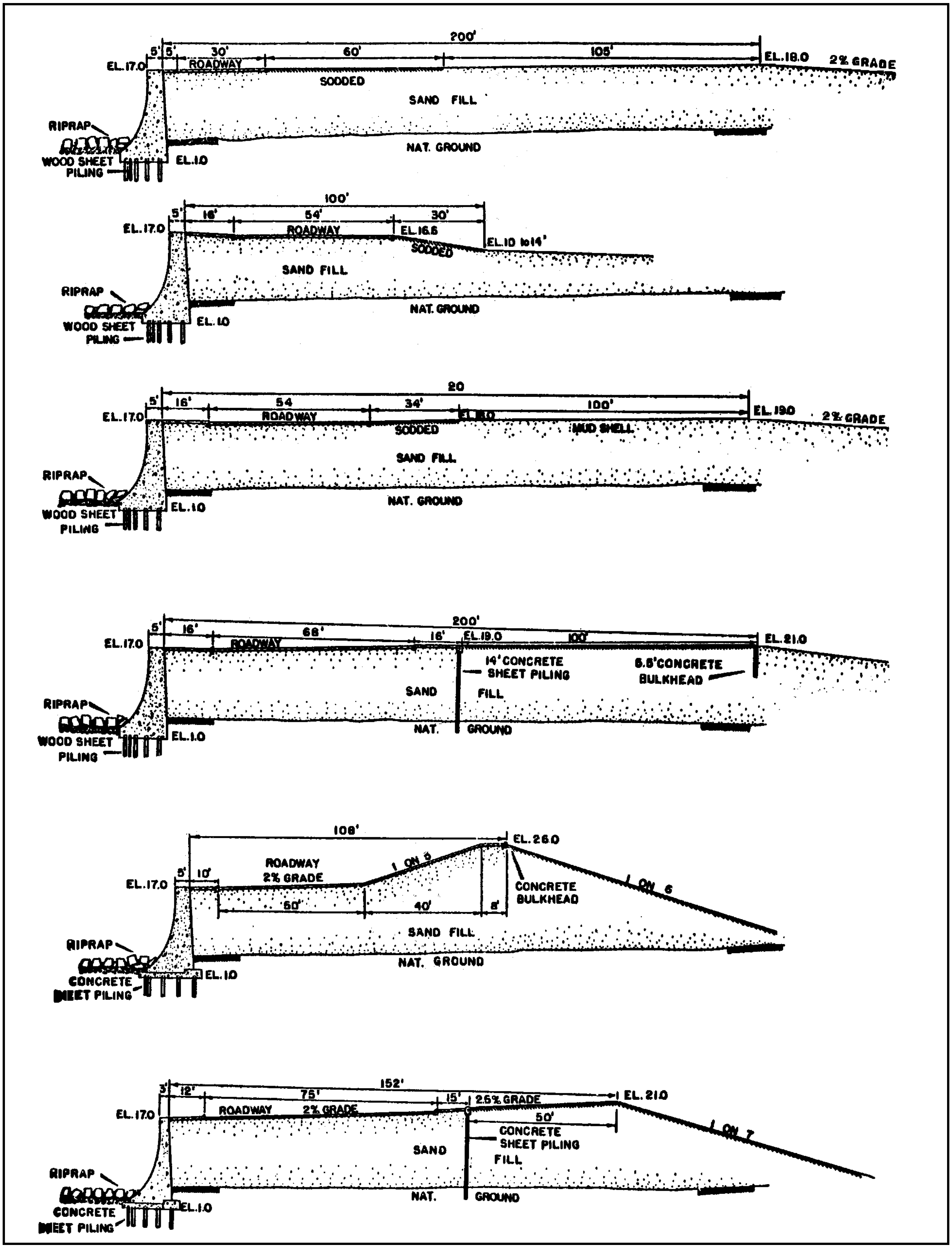
Figure V-3-4. Different types of seawalls and dikes (from Pilarczyk 1990)

a. Photograph of original construction (from USAED, Galveston)

Figure V-3-5. Galveston, Texas, seawall (Continued)

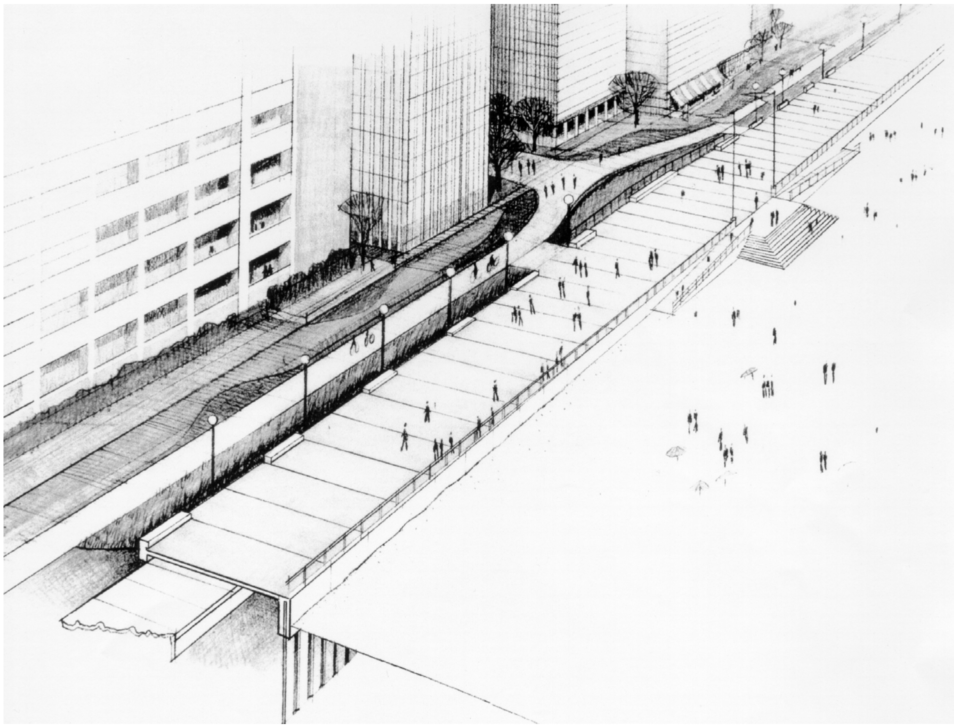
(a) The primary purpose of bulkheads is to hold land or fill in place and prevent shore side losses. A secondary purpose is to protect the land from wave attack. The strength of a bulkhead to protect against wave attack is provided almost solely by the fill, and if this material is lost, the bulkhead has no practical mechanism to adequately protect against waves. Therefore, two critical elements of a good bulkhead design that prevent or limit loss of backfill are: return walls at the alongshore ends of the structure to prevent high water from washing material away from behind the structure; and geotextiles to allow water but not fines to flow through the structure. Drainage of water through, behind, or laterally away from the structure is important to relieve pore pressure from excessive rainfall or overtopping. Drainage can be provided by drilling weep holes in the structure face to allow water to seep out.

(b) Steel and timber sheetpiling are the most commonly used bulkhead material. Steel sheet piles are individual sheets which can be interlocked and driven into hard, dense soils. The interlocking nature of individual steel sheet piles helps to limit erosion losses of backfill through the bulkhead. However, good design practice also includes installation of a geotextile or gravel filter between the bulkhead and the backfill to further prevent sediment losses. Filters are particularly important for timber bulkheads because they lack an interlocking mechanism, though overlapping timber sheets in a two-to-three layer technique can often limit the pathways for sediment to travel. An often encountered difficulty in installing geotextiles is depth of placement. For sheet piles that are driven, placing the geotextiles the full depth of the structure is practically impossible through the structure below the depth of the filter cloth. The loss of the backfill at a timber bulkhead from water (rain and/or wave overtopping) seeping and carrying sand through the bulkhead below the depth of the filter or below the depth of the timber piles is a common damage mechanism.



b. Chronology of development (from Weigel 1991)

Figure V-3-5. (Concluded)



a. Artist's perspective

b. Aerial photo

Figure V-3-6. Virginia Beach seawall/boardwalk, 1997 (courtesy City of Virginia Beach, VA)

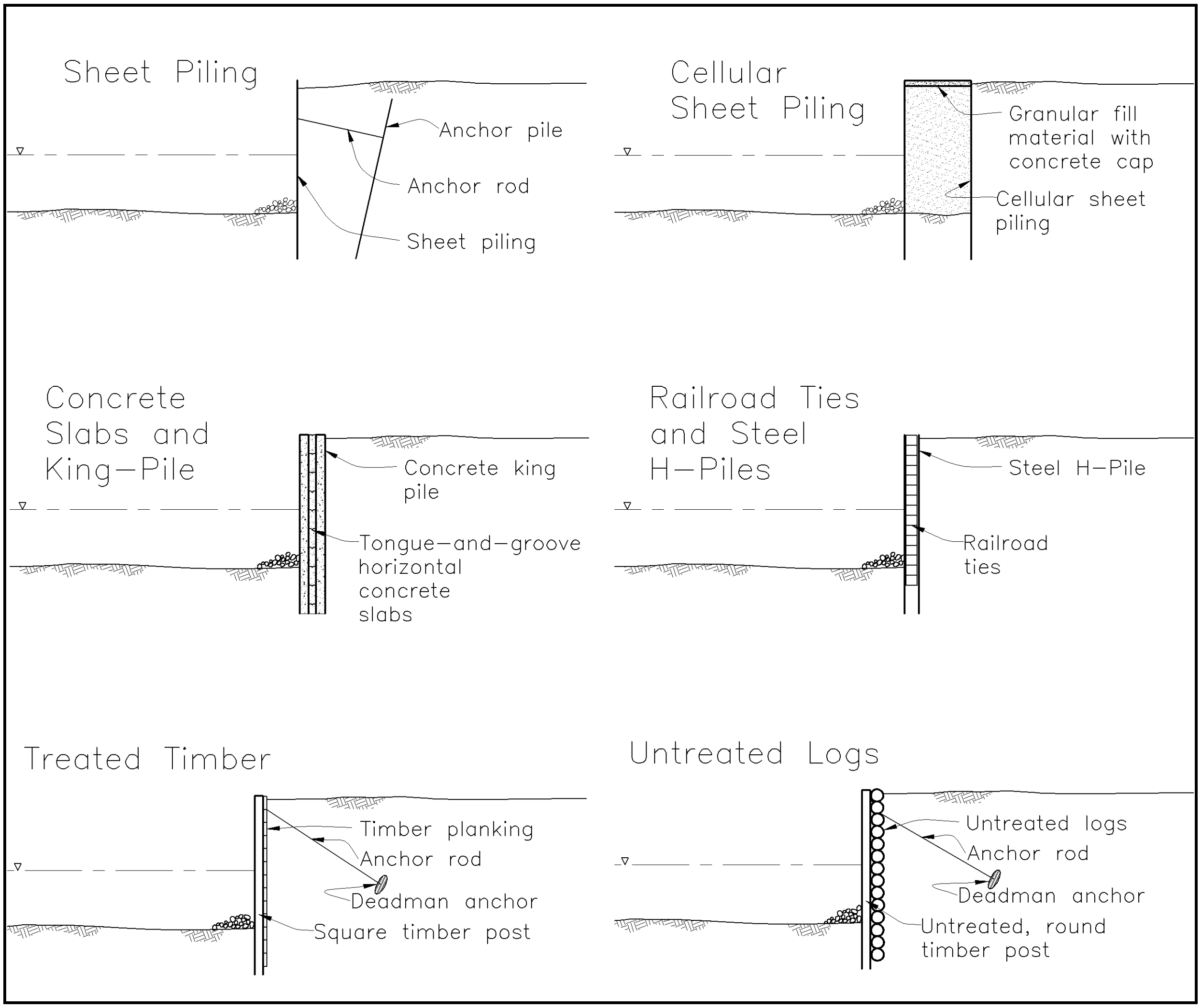


Figure V-3-7. Typical bulkhead types

(3) Revetments. Revetments are a cover or facing of erosion resistant material placed directly on an existing slope, embankment or dike to protect the area from waves and strong currents. Three major features are a stable armor layer, a filter cloth or underlayer, and toe protection. The filter and underlayer support the armor, yet allow for passage of water through the structure. Toe protection prevents undercutting and provides support for all the layer materials previously mentioned. If the toe fails, the entire revetment can unravel.

(a) Figure V-3-8 summarizes a wide range of designs and materials employed for a revetment. Armoring may be either flexible (normal) or rigid. Riprap and quarrystone designs can tolerate some movement and shifting or settling of their underlying foundation, yet remain functional. Rigid, concrete or asphalt slabs-on-grade are generally unable to accommodate any settling.

(b) Typical failure modes for revetment include:

- Armor layer damage and interior exposure.

- Overtopping and loss of foundation material.

- Toe failure and unraveling.

- Excess groundwater pressure and piping failure through the armor layer.

- Rotational sliding along the slip-circle surface

- Flanking of the end sections.

(c) Armor layer stability is discussed in detail in Part VI-5-3-a; toe stability and protection in VI-5-3-d, and filter layer design in VI-5-3-b. Shore protection by revetments can be for all levels of wave energy. For low wave energy environments in bays and rivers, relatively inexpensive and readily available stone sizes makes revetments a common choice for erosion protection by individual property owners. Vegetation and marsh grasses seaward of the revetment also diminish some wave energy to protect the revetment.

(4) Combinations and other types. Protective revetments on dikes are an example of combination coastal armoring structures. Earthen dikes, with stone revetments have been constructed to protect Texas City, Texas, and along the Lake Erie shoreline by the USACE. Due to the nature of the earthen structure, design and specifications should be evaluated by geotechnical engineers (see EM 1110-2-1913, "Design and Construction of Levees"). In the Netherlands, the sea side is heavily armored to protect the dike against the North Sea. On the land side, grazing sheep are used to continually compact the earth.

(a) As previously discussed, a storm surge barrier (see Figure V-3-1) across the opening to the sea provides alternative means of armoring for shore protection. The most notable hurricane barrier in the United States is located at New Bedford Harbor, Massachusetts. The tide (or flood) gate remains open for navigation, then closes to prevent flooding of inland areas during storms.

(b) When insufficient space or earthen dike materials are available, rigid, vertical flood walls may be constructed. Design guidance is available in EM 1110-2-2502, "Retaining and Flood Walls." Crossing the wall requires flood gates that roll, swing, or slide to close the opening EM 1110-2-2705, "Structural Design of Closure Structures for Local Flood Protection Projects." Special, interior drainage facilities may also be needed including pumping stations (EM 1110-2-3102, "General Principles of Pumping Station Design and Layout."). Grade raising, i.e., increasing ground elevation by filling with stable material is also possible. The entire city of Galveston, Texas, was elevated about 4 m to match the seawall crest elevation. (see Figure V-3-5). Sandy material was dredged from nearby Galveston Bay and pumped hydraulically to fill the island. Wiegel (1991) presents a complete history of the Galveston, Texas seawall.

b. Functional design.

(1) The functional design of coastal armoring structures involves calculations of wave runup, wave overtopping, wave transmission, and reflection. These technical factors together with economic, environmental, political (social), and aesthetic constraints all combine to determine the crest elevation of the structure.

(2) Wave runup and overtopping depend on many factors. Part VI-5-2 presents all the details. Empirically determined coefficients, formulas, tables, etc. have mainly come from laboratory scale experiments with irregular waves in large wave tanks. Independent variables include wave characteristics, water depths, slopes, roughness, degree of permeability or impermeable, wave angle, berm or continuous slope, freeboard, etc. Tables VI-6-18, 19, and 20 in Part VI-6 present partial safety factors for runup on rock-armored slopes, hollowed cubes, and dolosse armor units, respectfully.

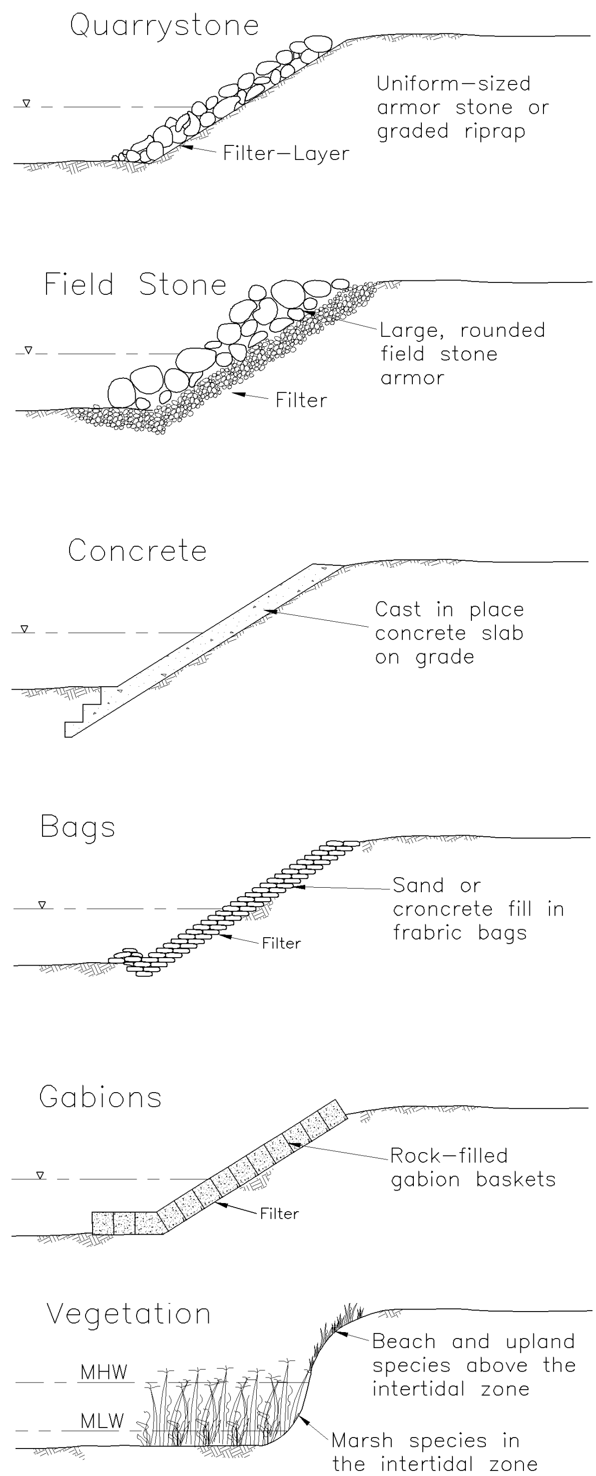


Figure V-3-8. Summary of revetment alternatives (continued)

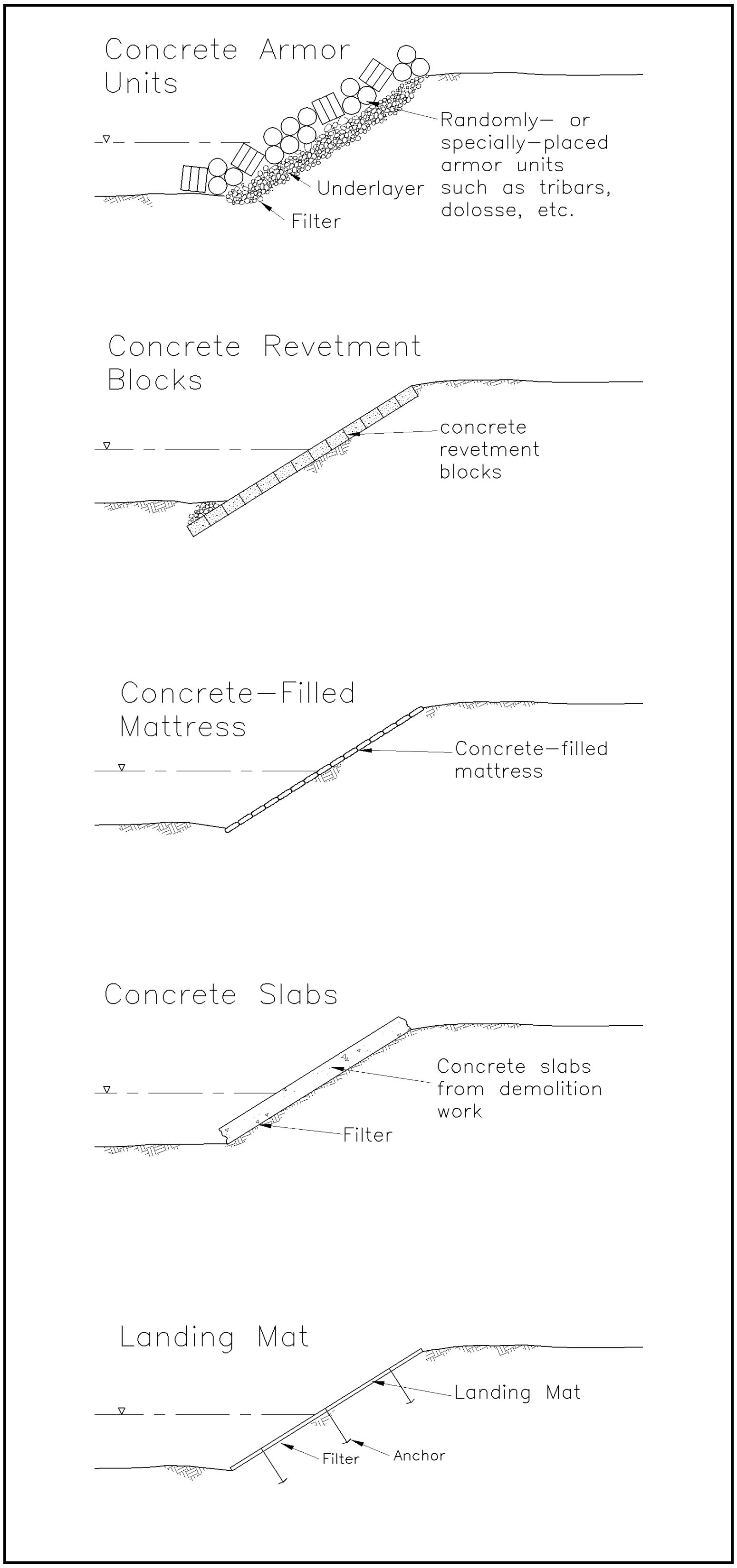


Figure V-3-8. (Concluded)